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COMPARISON OF THE DIGESTIBLE ENERGY (DE) AND NET ENERGY (NE) SYSTEMS FOR THE HORSE

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The horse can be described as a monogastric herbivore or a non-ruminant herbivore which is suited to the digestion and utilization of high fiber diets due to continual microbial fermentation primarily within the hindgut (cecum and colon). Domestication, and an increasing demand for horses to perform under circumstances that require energy intakes above those able to be provided by their more 'natural' diet of fresh forage, has resulted in the inclusion, in particular, of cereal grains and their by-products as well as supplemental fat in many horse diets. Such additions may be made in the form of the raw material or processed raw material or a manufactured compound feed. The upper part of the gastrointestinal tract has a relatively small capacity and the horse has digestive and metabolic limitations to high grain (high soluble carbohydrate) diets. Large grain meals may overwhelm the digestive capacity of the stomach and small intestine leading to the rapid fermentation of the grain carbohydrate in the hindgut. This may result in one of a number of disorders including colic, diarrhea and laminitis. Providing the right amount of energy from the appropriate sources without compromising the digestive system is therefore very important especially to the performance horse. Recently it has been suggested that the net energy system may be a more appropriate way of describing both the energy content of feeds as well as the energy requirements of horses. This paper will explore certain aspects of both the NE and the more traditional DE systems and will look at :

- Energy sources and how the horse obtains its energy from the different feedstuffs.
- Energy content of the different feedstuffs and its availability from such feedstuffs.
- Energy requirements.

Definition

A typical dictionary definition of energy would be 'Physics a. The capacity of a body or system to do work. b. A measure of this capacity measured in joules (SI) units.' Energy *per se* is therefore not a nutrient and the precise definition of energy, especially in a nutritional sense, may be complex.

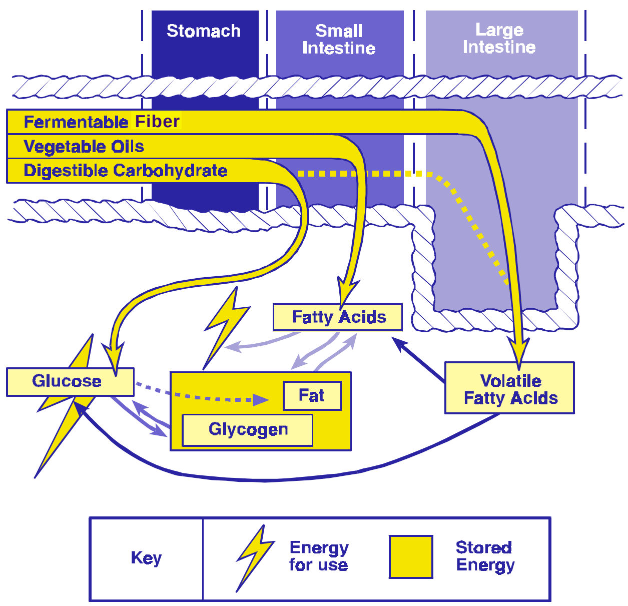
Energy Sources and Efficiency of Utilization

Practically, certain nutrients in a horse's diet provide the energy intake for that individual following conversion of their chemical energy to other forms of chemical energy, mechanical energy and heat. Dietary energy is provided to the horse by four principal dietary energy sources :

1) Hydrolyzable carbohydrates e.g. starch.
2) Cellulose, pectins, hemicelluloses, etc. (i.e. non-starchpolysaccharides: a component of dietary fiber).
3) Fats *(normally less than 3% total feed intake but most horses able to digest and utilize fat efficiently - not usually recommended to feed at more than 10% of the diet and any fat should be introduced gradually).*
4) Proteins *(not a nutritionally preferred option as an energy source: ergogenically inefficient; nitrogen must be removed, as excess protein is not stored, resulting in increased water requirements and potentially higher ammonia levels in the stable).*

In general, a high proportion of the available starch ingested is degraded to glucose before absorption in the small intestine (S.I.) (unless the digestive capacity of the S.I. is overwhelmed). However, a proportion of the starch and a varying proportion of the dietary fiber (depending on the extent of lignification) will be subjected to microbial fermentation. This occurs primarily in the large intestine, producing predominantly short chain or volatile fatty acids, some of which may be used directly as an energy fuel by the gut cells themselves while the majority is absorbed and converted to either glucose or fat .

Figure 1.



The fermentation process is ultimately less efficient than obtaining energy from carbohydrate sources directly via glucose. This helps explain why feeds with a high fermentable fiber content provide less useable energy than those feeds with a high digestible carbohydrate content. The extent to which cereal starch provides glucose or volatile fatty acids, as the end result of digestion, will depend on its prececal digestibility which, in turn, will vary according to the feedstuff under consideration and the extent and nature of the processing it has been subjected to. If excessive starch reaches the hindgut it will be rapidly fermented resulting in high levels of lactic acid and a number of potential adverse sequellae.

The main fuel sources available for energy production by the horse both at rest and during exercise are considered to be *carbohydrate* in the form of muscle glycogen or blood glucose; *fat* in the form of muscle or plasma triglyceride, plasma free fatty acids and muscle stores of *adenosine triphosphate* (ATP) and *phosphocreatine* (PCr) :

1. Anaerobic metabolism of glucose occurs more quickly but less efficiently (i.e. less ATP produced) than in the case of aerobic metabolism.
2. Fat can only be metabolized aerobically. This is comparatively slow but very efficient, with less of the gross chemical energy being lost as heat.
3. Energy is very quickly available from the very limited stores of ATP and PCr.

There are a large number of factors that affect the proportion of energy that can be derived from each potential energy source, during different energy bouts, including:

1. The intensity and duration of exercise;
2. The muscle fiber composition of the horse;
3. The diet and the fitness (coupled with the training regimen) of the horse.

It has been suggested that plasma free fatty acids are quantitatively the most important energy source (especially during submaximal exercise) in the horse; but as the intensity of exercise increases, the relative contribution of fat to total energy production decreases so that during very high intensity exercise, the catabolism of carbohydrate accounts for the majority of energy.

Energy Content of Feedstuffs

At present there are three main ways to describe the energy potential of a horse feed: total digestible nutrients (TDN), digestible energy (DE) and net energy (NE). Each of these has been determined in a number of ways over the years with TDN becoming less popular recently. Further confusion results from the fact that two units of energy are in common use in the horse industry: the joule (J) predominantly in Europe and the calorie in the United States (4.184 J is taken to be equivalent to 1 calorie).

Figure 2.

GROSS ENERGY (GE)

↓ ***Minus fecal loss***

DIGESTIBLE ENERGY (DE)

↓ ***Minus loss as gas and in urine***

METABOLIZABLE ENERGY (ME)

Allows for efficiency of energy utilization ↓ ***Minus loss as waste heat***

NET ENERGY

= energy available for life and movement

The energy value of any feedstuff, as well as the total diet, for the horse will depend upon the relative amounts of hydrolyzable and fermentable substrates that it contains. Determination of a feed's energy value using *in vivo* methods, especially in the horse, tends to be time consuming, labor intensive, costly and often highly impractical. Therefore, as with many other species, effort has concentrated on finding methods for assessing the energy values of feeds using prediction equations. At the moment these tend to be based on the chemical composition of the feed, which may not truly reflect its functional aspects.

TDN

The energy content of rations has been calculated as the percent total digestible nutrients in a number of ways as illustrated in Table 1. Conversion factors have been used to convert TDN values to today's more commonly used DE values. These may not be appropriate. The most frequently used factor is based on work in ruminants which resulted in an average conversion factor of 2000 kcal of DE being equivalent to 1 lb TDN or 4.41 Mcal DE/kg TDN. However, subsequent work in ruminants suggested that this conversion factor was strongly influenced by the level of digestible protein. In the horse limited work in this area has been carried out, but in one study of five pony stallions the DE to TDN relationship was found to be 4.648 Mcal/kg for a hay diet and 4.624 Mcal/kg for a hay and concentrate diet with similar crude protein levels (Barth et al., 1977), suggesting that the 4.41 conversion factor could result in substantial errors.

DE

Most commonly the energy content of horse feed is referred to by its DE or digestible energy content, i.e. fundamentally the gross chemical energy in the feed minus the energy lost in the feces. Using standard digestibility balance studies,

Table 1.

Examples of equations that have been used to determine TDN and DE from the chemical composition of feed include:

a) TDN = % DCP + % DNFE + (%DEE x 2.25)
   DE = 2 x TDN (%) in Mcal/kg

b) TDN = 78.1 - (1.01 x ADF %) + (0.823 x CP %)
   $DE = 0.255 + \frac{(0.0366 \times TDN\ \%)}{2.2}$

c) DE (kcal/kg DM) = 2118 + 12.18 (CP) - 9.37(ADF) -3.83(NDF- ADF) + 47.18(fat) + 20.35(NSc) - 26.3(Ash)

d) DE (MJ/kgDM) = DCP x 0.023 + DEE x 0.0381 + (DCF+DNFE) x 0.0172

e) $DE\ (MJ/kg\ DM) = 11.1 + 0.0034\ CP + 0.0158\ CF - 0.00016\ CF^2$

DCP = Digestible crude protein	ADF = Acid detergent fiber
DNFE = Digestible nitrogen free extract	NDF = Neutral detergent fiber
DEE = Digestible ether extract	DCF = Digestible crude fiber
NSc = 100 - CP - EE - NDF - ash	CP = Crude protein
	CF = Crude fiber

the digestible energy content of a ration can be estimated *in vivo*. This does not provide a truly accurate measurement because fecal energy includes energy originating from endogenous sources as well as undigested feed and bacteria. It is nevertheless a very useful practical guide. However, this is an expensive and time consuming way to determine DE and so a number of equations to estimate DE content of feedstuffs have been quoted in the literature (see Table 1 for some examples) and continual modifications are being proposed to improve the predictive nature of these equations.

Net Energy

The DE system tends to overestimate the actual mechanical energy potential of a high fiber feed compared with a high soluble carbohydrate feed, as fiber predominantly produces VFAs which are not used as efficiently as glucose. The French Net Energy system (primarily developed by the Institut National de la Recherche Agronomique [INRA]) was developed to allow for the differences in utilization of the metabolizable energy available from different feeds, depending on the proportion of the end products of digestion produced and the biochemical pathways used by these end products to produce mechanical energy (as outlined above).

It uses the horse feed unit (HFU) or in French, l'unite fouragire cheval (UFC). The UFC corresponds to the net energy value (2250 kcal) of one kg standard barley (87% DM) in a horse at maintenance. The UFC value of a particular feed is calculated by dividing its NE content in kcal by that of barley, i.e. 2250.

The NE UFC/kg DM for corn, barley, oats, maize silage, hay and straw are 1.35, 1.16, 1.01, 0.88, 0.53 and 0.28, respectively.

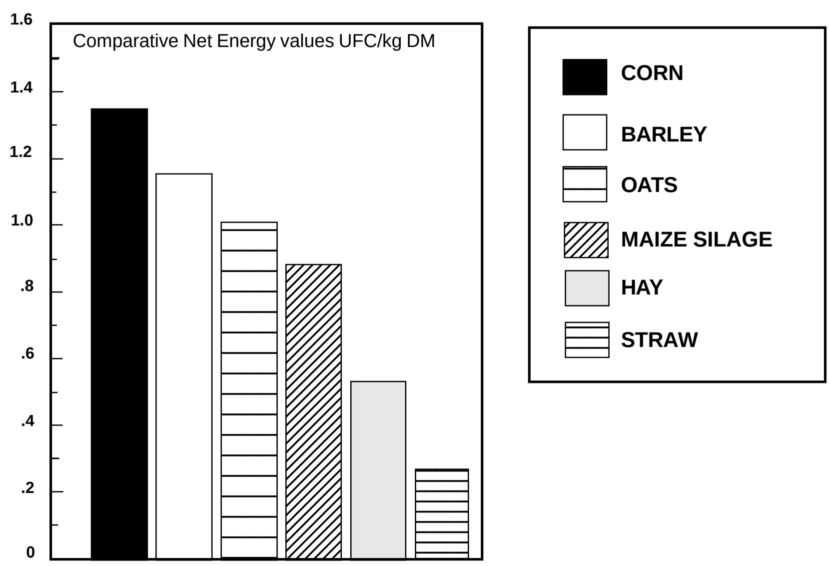
Comparing this system with the DE/ME system, the energy value of straw for example has been reported to be 41% that of barley using DE values, 37% that of barley using ME values and 29% that of barley using NE. Using this as an extreme example, if a 500 kg horse was being fed 3 kg barley and 7 kg hay and one wanted to replace the barley, *in energy terms*, with straw :

- Using DE values one would calculate having to feed about 7.5 kgs of straw.
- Using NE values (to get the same useable energy) one would calculate having to feed about 10.5 kgs of straw.

The discrepancy between the actual energy value to the horse for different feeds as calculated by these various methods increases as the cell wall contents increase. So if you fed a diet which contained certain high fiber feedstuffs according to its DE value you would tend to overestimate the actual useable energy available from that diet and the horse might either lose weight or lack sufficient energy.

For the purpose of this paper the NE value for oats (as fed) according to the French Net Energy system is taken to be ~2.0 MCal/kg and for hay ~1.0 – 1.25 Mcal/kg.

Figure 3.



Net Energy Available to the Horse from the Diet

A number of methods or models have been used to estimate the energy partitioning of a diet and therefore the energy available. Most of these rely on a mixture of calculated, determined and assumed efficiency factors and have not been validated fully under field conditions. However, they provide at the moment the most reliable way of determining the true or net energy available from a diet.

The UFC of forages or concentrates (raw materials), it is suggested, can be predicted directly from their chemical composition, although these predictive values are more accurate if the DE is known (Martin-Rosset et al., 1994.):

1. Forages
   UFC = 0.0557 + 0.0006 CC + 0.2489 DE (r^2 = 0.996)
   UFC = 0.825 - 0.0011 CF + 0.0006 CP (r^2 = 0.69)
2. *Concentrates* - raw materials
   UFC = -0.134 + 0.0003 CF -0.0004 CP + 0.0003 CC + 0.3160 DE
   (r = 0.99)(where CC = cytoplasmic carbohydrate, CP = crude protein, CF = crude fiber).

It should be noted, however, that an additional correction has been recommended for high fat diets. For compound feeds it has been suggested that the UFC value can also be predicted (Martin-Rosset et al., 1994) from chemical composition using a number of equations. The difference between the values obtained using a composite equation and the addition of the individual feed component UFC values is said to be between 0.2-1.3 UFC/100 kg organic matter.

The French Net Energy system (an empirical system) for calculation is illustrated in Figure 4 and can be compared with a partitioning model (a more physiological system), as illustrated in Figure 5, for determining NE, ME, and DE values (Kronfeld, 1996). ***The net energy values can be directly compared only for maintenance, but not for work, as explained below.*** Using one of the suggested composite equations appropriate for forages (Martin-Rosset et al., 1994) or the system outlined in Figure 4, the net energy available for maintenance from a 100% ‘average’ timothy hay works out to be around 5.2 MJ/kg which is very close to that predicted, using the partitioning system (Kronfeld, 1996) for a similar timothy hay diet of around 5.4 MJ/kg. Similarly a compound feed with fat supplementation gives a French Net Energy value of around 9.5 MJ/kg for maintenance compared with 9.3 MJ/kg derived using partitioning. Further comparisons need to be made both theoretically and in the field before conclusions can be made as to which system provides an overall advantage.

Unfortunately accurate digestibility data for the various different energy sources within different feeds are not currently available, and the effect of different feed types and processing techniques on energy availability are not fully understood. Therefore, the amount of energy each nutrient type within a particular ration will really provide to an individual animal cannot be accurately determined. Differing analytical methods and terminology used also add to the confusion. Both systems, as illustrated in Figures 4 and 5, therefore can only provide a guide to the energy content of a diet.

Energy Requirements for Maintenance

Definitions include 'the daily food intake that maintains constant body weight and body composition of a healthy adult horse with zero energy retention at a defined level of activity in comfortable surroundings.' Several equations for estimating maintenance energy requirements have been derived over the years and will not be discussed in detail here. A number of factors including the individual, body composition, gender, environmental temperature, whether in work or not, age, lifestage, breed, temperament and season may affect actual maintenance energy requirements.

Energy Requirements for Exercise

Many factors also influence the additional requirements for exercise including:

- Weight of the rider;
- Weight of the tack;
- Ability of the rider;
- Degree of fatigue;
- Condition and training of the animal;
- Diet composition and
- Environmental conditions.

In addition, the nature of the exercise itself will vary according to its intensity, duration and contour (terrain).

The efficiency of the conversion of chemical energy (derived ultimately from the diet) to mechanical work (work efficiency or k_w) is only about 20-25%. Most of the energy released appears as heat.

Figure 4 (page 207)**:** System for determining the net energy of a diet using the French Net Energy system devised by INRA (based on Martin-Rosset *et al.*, 1994). Examples only of the various equations available are given.

Figure 5 (page 208)**:** System for determining the net energy available from a certain diet (in MJ) *for maintenance* based on a physiological partitioning system (Kronfeld, 1996), on an as-fed basis.

Figure 4.

Gross Energy (GE)

Forages

- Predicted from the CP content
- Conversion factor will vary according to type of hay

Concentrates

GE = 5.72 CP + 9.5 EE + 4.79 CF + 4.17 NFE + 'A'

The 'A' values depend on the kind of feed cereals

↓

Digestible Energy (DE)

- Predicted from GE and the digestibility of energy (dE) efficiency factor

dE = 0.0340 + 'B' + 0.9477 x digestible organic matter

B = +1.1 for concentrates: -1.1 for forages.

dOM can be predicted from crude fiber content for forages to some degree

dOM for concentrates need to be drawn from tables

$$DE = \frac{GE \times dE}{100}$$

↓

Metabolizable Energy (ME)

For all feeds

100 (ME/DE) = 84.07 + 0.165 CF - 0.276 CP + 0.184 CC

For protein rich feeds ³ 30% CP on DM basis

100 (ME/DE) = 94.36 + 0.110 CF - 0.275 CP

ME/DE » 0.78 - 0.8 for oil meals

0.91 wheat straw

0.84 - 0.88 hays

0.90 - 0.95 for cereals → \ for feedstuff ME = $\frac{ME}{DE}$ ratio x DE value for that feedstuff

↓

Net Energy (NE)

NE = (ME x efficiency of ME utilization [k_m] = X

$$NE\ (UFC) = \frac{X}{2250}$$

k_m varies with feed composition and is predicted from the chemical composition, e.g.

Forages

$100k_m$ = 57.56 - 0.0110 CF + 0.0105 CP + 0.0270 CC + 0.0150 DOM

$100k_m$ = 71.64 - 0.0289 CF + 0.0148 CP

Cereal by-products

$100k_m$ = 94.41 - 0.0237 OM - 0.0022 CP + 0.0121 CC

$100k_m$ = 82.27 - 0.0248 CF - 0.0160 CP

continued

Example for Barley

GE = 3854 Kcal/kg
dOM = 0.83 (from Tables) \ dE = 0.8 DE = 3076 Kcal/kg
ME/DE = 0.93 \ ME = 2864 Kcal/kg
km = 0.785 \ NE = 2250 Kcal/kg
1 UFC = 2250 Kcal NE

CP = Crude protein, EE = Ether extract, CF = Crude fiber, NFE = Nitrogen free extract
CC= Cytoplasmic carbohydrates
dOM=Digestible organic matter
OM = Organic matter

Figure 5.

Gross Energy/Intake Energy (IE)

- Calculated from the relative proportion of fat, carbohydrate and protein using conversion factors (heats of combustion) of 38.9, 17.5 and 23.7 KJ/g respectively

↓

Digestible Energy (DE)

- Using estimated digestibility factors (K_d = DE/IE) - various estimates from other experiments
- Factors will vary according to nature of diet
- Factors of 0.74 and 0.65 x IE for protein and fat respectively for a diet without supplemental fat
- Factors of 0.61 and 0.82 x IE for protein and fat respectively for diet with supplemental fat
- Factors of 0.8 x IE for NSC
- Factors of 1.0 x IE for CHO-H ie where hydrolyzable carbohydrate CHO-H = nonstructural carbohydrate (NSC) x 0.8
- Factors of 0.25 - 0.5 x IE for fermentable carbohydrate where fermentable carbohydrate = NDF + 0.2 x NSC)

↓

Metabolizable Energy (ME)

- Takes into account energy loss in gas produced during fermentation as well as via urea in the urine
- 0.78 x DE for protein (loss of energy as urea)
- 0.95 x DE for fermentable carbohydrate (loss of energy as methane)

↓

Net Energy Available for Maintenance (NE)

- Uses estimated efficiency factors (K_m)
- K_m 0.7; 0.89; 0.85 and 0.63 x ME for amino acids, long chain fatty acids, glucose, short chain fatty acids respectively

↓

NB. Amount of energy available for the work of maintenance or exercise will depend on the exercise undertaken and the heat produced ie K_w may not be the same as K_m.

↓

Net energy available for work (NE_w)
K_w of 0.228 for glucose oxidation : 0.245 for long chain fatty acid oxidation

Digestible Energy Requirements

DE requirements can be worked back from the energy expenditures. Alternative guidelines have been given for directly determining the DE requirements for different types of physical activity on a minute-by-minute basis or even more general empirical equations can be used. The following equation, for example, was produced for horses whose work load (kg x km) was not greater than 3560 (i.e. not applicable to endurance horses) and whose body weight was maintained (Anderson et al., 1983). This therefore assumes that this body weight was desirable:

$$DE\ (Mcal/day) = 5.97 + 0.021W + 5.03X - 0.48X^2$$

(where W = body weight in kg : X = Z x distance travelled in km x 10^{-3} :
Z = weight of horse, rider and tack in kg.)

Such an equation makes no allowance for speed which may be important in the horse.

The NRC (1989) suggests even more general equations as a guide:

- Light work (e.g. pleasure riding, bridle path riding, etc.) 1.25 x Maintenance DE
- Moderate work (e.g. ranch work, jumping, etc.) 1.5 x Maintenance DE
- Intense work (e.g. racing, polo, etc.) 2 x Maintenance DE

Net Energy Requirements

Estimated net energy requirements, in addition to the daily maintenance net energy requirements, for a number of types of work (based on work by INRA) are shown in Table 2. It is not possible to directly compare these net energy requirements with those derived based on the partitioning system described above (Kronfeld, 1996) because the French Net Energy system assumes the same efficiency for work (K_w) as for maintenance (K_m), i.e. $K_w \sim K_m$, whereas in the partitioning system, K_w (~ 0.2 - 0.25) is taken to be much lower than K_m (~ 0.7 - 0.8). i.e. the French NE system states that the NE value for hay is around 1.0 – 1.25 Mcal/kg whether the hay is used for work or maintenance whereas in the partitioning system hay has a value of around 1.29 Mcal (5.4 MJ) for maintenance and only 0.39 MCal (1.63 MJ) for work. Because the requirements are estimated using the same assumptions, those made under the French Net Energy system appear far higher than those estimated using the partitioning system (see examples page 210).

Table 2.

Type of Work	Guide to Mcal Net energy requirements/hr
Very light (@ 50% walk 50% trot)	0.45 - 1.125
Light lesson (@ 50% walk 40% trot 10% canter)	2.25 - 3.375
Moderate lesson (@ 20% walk 10% canter 10% jumping 60% trot)	3.375 - 4.5
Hard lesson	5.625 - 6.75
Light hack >3hrs/day (@ 90% walk 10% trot)	1.125
Light short ride 1-2hrs/day (@ 50% walk 45% trot 5% canter)	3.375
Moderate outdoor training (@20% walk 10% jumping 15% cantering 45% trot)	4.5 - 5.625
Intense training/competition (@ 10% walk 15% cantering 15% jumping 40% trot)	5.625 - 7.895

Estimated net energy requirements needed to be added to the daily maintenance requirement based on a 560 kg body weight horse carrying a 100 kg load (INRA 1984).
NE requirements for maintenance according to (Martin-Rosset et al., 1994)
(Kcal/day) [ab]NE = 84 $W^{0.75}$
or (UFC/day)[ab]NE = 0.038 $W^{0.75}$
[a] + 10-20% for stallions [b] + 5-15% for working horses to take into account the rise in overall energy metabolism, where W = Body weight (kg).

Practical Application

The three-day event, and in particular the cross-country day, is one of the most demanding equestrian sports and provides an indication of the energetic load of horses working at different speeds. Using a number of assumptions and theoretical calculations, the metabolic energy (ME) requirements of the various stages of the cross-country day have been estimated for a 575 kg (total weight + rider) horse: Phase A ~7.9 MJ; Phase B ~ 6.2 MJ; Phase C ~ 17.25 MJ & Phase D (the cross-country phase) ~ 13.45 MJ. Total 44.8 MJ ME. Overall, it was estimated that the total energy expenditure (ME) was 44,850 kJ if no allowance for jumps was made and 46,151 kJ if such an allowance was made (Jones & Carlson, 1995).

Using this example as above, it has been suggested that if the 44.85 MJ of ME was used with 20% efficiency (i.e. $K_w = 0.2$) it would mean that 8.97 MJ of energy had been available for work (i.e. net energy), the remainder being lost in heat production. If higher K_w values are used, then obviously a greater percentage would have been used for work (Kronfeld, 1996), e.g. if the 44.8 MJ of ME was used with 24% efficiency it would mean that ~11 MJ of energy had been available for work (i.e. net energy), the remaining *nearly three quarters being lost in heat production*.

In reality (Jones & Carlson, 1995) the expenditure in the field is likely to be higher than that predicted because additional energy will be required to overcome wind resistance, raise and lower the center of mass with the terrain, allow for periods of deceleration and acceleration, allow for horizontal translation over a jump and so on. Such allowances would need to be made if more accurate estimates are to be established, but these estimations provide very good baseline data.

A partition model based on the NE requirements of a 500 kg horse undergoing the cross-country phase of the three-day event as described above is illustrated in Figure 6. The values for ME, DE, and GE demonstrated (Kronfeld, 1996) were calculated based on a net energy requirement of around 11 MJ for the competition work and efficiency factors based on a diet comprised of 45% timothy hay, 45% oat grain and 10% vegetable oil (taking CP = 8.9%; fat 13.1%; hydrolyzable carbohydrate 22.3% and fermentable carbohydrate 42%). Several assumptions were specified for the model and efficiency factors were selected that applied to this diet. However, it gives a good illustration of how energy partitioning in a competition horse fed a likely competition diet may occur. In practice many such three-day event horses would be fed proportionally more hydrolyzable carbohydrate and less fermentable carbohydrate and not all the energy used would be expected to have been provided that day.

When similar calculations as used in Figure 6 were, however, applied to a 100% timothy hay (CP = 8.6%; fat 2.3%; hydrolyzable carbohydrate 12.8%; fermentable carbohydrate 59.8%) diet they showed that in order to provide the same net energy (required for maintenance, other work as well as the actual competition), an intake energy of 348 MJ would have been required from the hay diet. This corresponds to an intake of around 22 kg of hay or ~ 4.5% body weight. Horses would not be able to ingest as much hay as this daily, which helps to explain why hay only diets are unsuitable for intensively exercising animals.

The relative value of replacing hay with cereal grains and fats to meet the energy requirements for strenuous exercise appears to be explained, in principle, better by the NE system than by the more commonly used DE system.

This example provides support for using the net energy system which enables different feedstuffs to be compared directly according to their ability to provide mechanical energy. As stated above, this approach relies on knowing the NE requirements for the various exercise patterns and these are not currently readily available. In addition it relies on both the requirements and the availabilities from the feed having been determined using the same criteria,

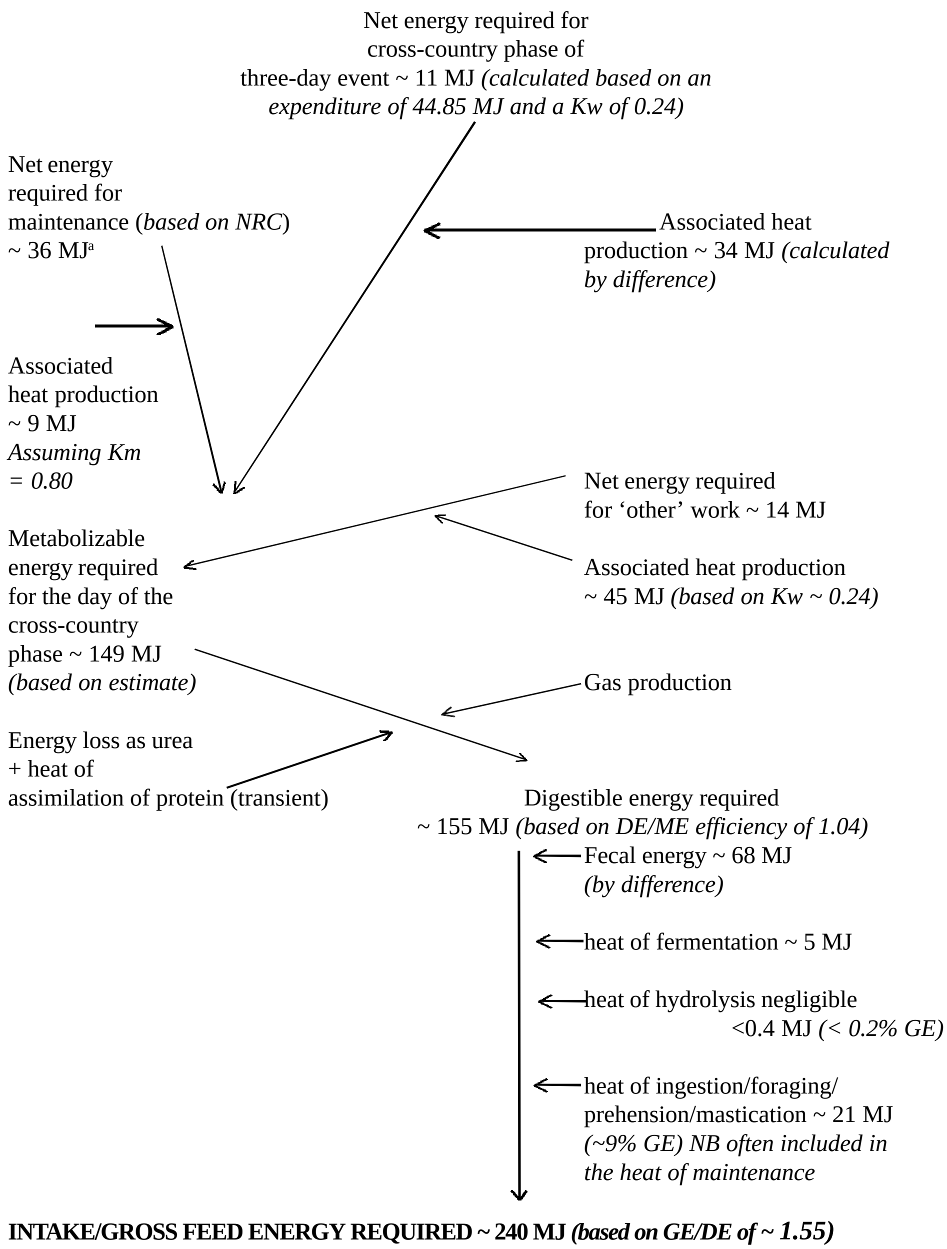


Figure 6. Schematic picture to illustrate how the amount of gross energy required from a particular diet can be determined if the net energy requirements for work and maintenance are known or can be calculated. Based (Kronfeld, 1996) on a 500 kg horse competing in the cross-country phase of a three-day event being fed a diet of 45% timothy hay, 45% oats and 10% vegetable oil. [a]Probably underestimated as the maintenance requirements of exercising horses may be higher than those of sedentary animals.

i.e. both determined via the French Net Energy system or the partitioning system. Mixing systems for determining the net energy available from food or required from food for exercise at present is likely to cause more confusion as outlined below

Practical Examples of Differences Between Partitioning and French Net Energy System

The 575 kg (total weight + rider) horse in the three-day event example above requires, based on the partitioning system, about 6 Mcal (25 MJ) of net energy for all activity (above maintenance) compared with a similar-sized horse undertaking 90 min work at a moderately intense level based on the French Net Energy system having additional (above maintenance) net energy requirements of around 9 Mcal (38 MJ) (assuming that this includes the allowance for the warm-up period, recovery period, etc.).

Daily net energy requirements, using the French Net Energy system, of around 6.9 UFC or 20.25 MCal or 84.7 MJ/day for a 500kg horse undertaking 2 - 4 hours outside exercise have been reported (INRA, 1990). Such net energy intakes would be difficult to achieve unless the net energy values of feeds for work are considered to be equivalent to those for maintenance, which is the case for the French Net Energy system, but not the partitioning system described by Kronfeld. Each system therefore at present must be used in isolation, which may cause confusion as illustrated in the following example:

1. French system:
According to Table 2 the NE requirements for a 560 kg horse plus rider undergoing 2 hours worth of moderate exercise are:

- Maintenance = (84 x 115) + 10% = 10.6 Mcal (44.35 MJ)
- Work = 2 x 4.6 = 9.2 Mcal (38.5 MJ)

TOTAL = 19.8 Mcal (82.84 MJ)

According to the French system:

- Good hay provides about 1.25 Mcal NE/kg
- Oats provide about 2.0 Mcal NE/kg

In a 50:50 mix – total intake 12 kg

- Hay provides 6 x 1.25 = 7.5 Mcal
- Oats provide 6 x 2.0 = 12 Mcal

TOTAL = 19.5 Mcal = very close to requirements.

2. Partitioning system
IF USE SAME REQUIREMENTS (i.e. French NE requirements) and 50:50 diet hay and oats
Maint = 10.6 Mcal

- Hay provides 1.29 x 3.2 = 4.13 Mcal
- Oats provide 2.0 x 3.2 = 6.4

TOTAL very close to requirements
Work = 9.2 Mcal

continued

· Hay provides 0.39 x 2.8 = 1.1
· Oats provide 0.62 x 2.8 =1.9
TOTAL = 3.0 Mcal **ONE THIRD OF ESTIMATED REQUIREMENTS**

An owner would need to feed more than 11 kg of hay and 11 kg of oats to meet the calculated French requirements if using the partitioning estimates of feed NE content. In the partitioning system less energy would have been calculated as being required for work (ie. 20-25% of the ME rather than 70-75%).

Present Disadvantages of the NE over the DE System

The net energy system has a number of potential advantages, but at the moment an English version of all the tables and factors used is not readily available; most countries use the DE system and DE values for horse feedstuffs are more routinely available. The NE system relies on the fact that maintenance requirements for energy account for the largest part of the total energy requirement which may not be true for certain performance animals. It also assumes that the UFC value for a particular feed is the same for maintenance as for work, which due to the increased heat production associated with work, may not be a valid assumption as discussed. The use of a NE system also implies amongst others that the NE requirements of the horse have been accurately described. Certain of the equations used to predict ME and therefore the NE values of feeds, etc. appear to have very low correlation values ($r^2 = 0.45$), whereas others as illustrated above are very high and at present full justification of their use does not appear to be available. However, it is possible, as more information becomes available, that this system will become more generally applicable and widely used.

Conclusion

Although much more work is needed before we fully understand the energy requirements of the exercising horse and how we can optimally manipulate the diet to provide this level of energy, there have been a number of useful developments in the last few years. The relative value of replacing hay with cereal grains and fats to meet the energy requirements for strenuous exercise appears to be explained, in principle, better by the French NE system or the energy partition model than by the more commonly used DE system. Work is needed to enable the NE system to be more widely applicable. In a number of other areas a unified approach would help to minimize the confusion currently present and help maximize progress in this area.

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